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QUARTERLY PROGRESS REPORT I

ELECTROMAGNETIC DEEP-PROBING (100-1000 KMS) OF THE EARTH'S INTERIOR FROM ARTIFICIAL SATELLITES: CONSTRAINTS ON THE REGIONAL EMPLACEMENT OF CRUSTAL RESOURCES

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(E81-10046) ELECTROMAGNETIC DEEP-PROBING (100-1000 KMS) OF THE EARTH'S INTERIOR FROM ARTIFICIAL SATELLITES: CONSTRAINTS ON THE REGIONAL EMPLACEMENT OF CRUSTAL RESOURCES Quarterly Progress Report, 1 Jul. - 30 Sep. G3/43 N81-13406 Unclas 00046

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Statement of Work

Objective

The objective of this investigation is to evaluate the applicability of electromagnetic deep-sounding experiments using natural sources in the magnetosphere by incorporating Magsat data with other geophysical data.

Approach

The investigator shall pursue the above objective through an analysis of Magsat satellite data, ground-based magnetic observations, appropriate reference field models, and other satellite data.

The objective will be pursued by seeking the optimal combination of observations which lead first to a global, and then to a regional, characterization of the conductivity of the Earth's upper mantle.

Tasks

The following tasks shall be performed by the investigator in fulfillment of the above objective:

a. Use data from Magsat satellite to constrain a long-period global "response function" for the average Earth at low latitudes over a period ranging from 6 hours to 27 days.

b. Synchronize the Magsat data with low-latitude ground-based observatory data to determine the vertical gradient of the respective magnetic field components. Use the vertical gradient of the appropriate components to independently ascertain the separation of external and internal field contributions.

c. Segregate the Magsat electromagnetic "response functions" according to the tectonic regime at the Earth's surface and evaluate systematic differences between regions having lateral scale sizes on the order of 1000 km or greater.

d. Theoretically evaluate problems of resolution and interpretation involving electromagnetic induction by temporally and spatially-varying magnetospheric sources in a rotating inhomogeneous Earth as observed at arbitrary points in space. Use these theoretical studies to constrain the interpretation of Magsat data as well as to propose further applications of satellite-based electromagnetic deep-sounding experiments.

e. Integrate the regional response functions with other geophysical data in order to constrain the joint interpretation of comprehensive physical models.

f. Prepare and submit to NASA periodic progress reports and a detailed final report documenting the results of this investigation.

FOCUS OF ACTIVITY

Personnel

This quarter we have mobilized personnel for this project and hired a Geophysical Data Analyst (Michael Rossen) to assist in computer program development and the analysis of data. Mr. Rossen, a Physics graduate, will be supported in part from the NASA/MAGSAT program.

Analysis of Ground Based Observatory Data (Task B)

Activity has focussed on developing a strategm for interfacing ground-based observatory data with the satellite data. We have analyzed the latitudinal dependence of magnetic storm disturbances for periods available from the World Data Center (1965 and 1967) in an effort to ascertain the suitability of assuming a P_1^0 harmonic dependence for the source field.

Problem: The dynamic source field seems to have a much more complicated spatial and temporal dependence than global induction workers have hitherto assumed.

Attempted Solution: We are attempting to synthesize a dynamical field model at high sampling rates (1 min. to 2.5 min.) which can be compared with the satellite data in the satellite frame of reference.

Theoretical Model Simulation (Task D)

We are in the process of evaluating the coupling of lateral heterogeneities within the earth (e.g. oceans) to source fields of finite dimensions. The vector components of the disturbance field are to be calculated at ground-level and at the satellite. The results of this calculation will provide a basis for deciding the optimal use of ground-based observations to a) minimize noise at the satellite altitude; b) the feasibility of evaluating a globally averaged response function for a laterally heterogeneous earth; c) methods for regionalizing the response function of the earth to analyze lithospheric tectonics.

Problem: The theoretical analysis in three-dimensions of global sized heterogeneities and arbitrary source-fields, easily over-runs the capability of most computer systems, particularly to model small scale features (the ocean-land interface) in the global framework.

Solution: We have reduced the problem to a two-dimensional model which seems to be valid at the depth of penetration and radius of curvature relations which pertain. This has to be evaluated! We are beginning this analysis with the E-polarization mode and will be looking at some very simple source field and geometrical relationships to gain insight into the problem.

Interaction with Other Workers

The Principal Investigator conferred with Joe Cain when visiting Denver on other business and was appraised of certain problems of low-amplitude noise on the MAGSAT data. Because of the relatively low level of magnetic disturbance during the MAGSAT mission we are postponing the actual analysis of any MAGSAT data until the noise problem is minimized.

Filtering programs, developed by our group, for the analysis of space/time series have been forwarded to Dr. Cain and are available for use by other MAGSAT investigators. Program listings are attached.

```
      SUBROUTINE FILT(X,N,DEL,FRQ,PASS,HIPASS,XX,W)
C     X IS THE ORIGINAL DATA
C     THE SUBROUTINE CONVERTS X(I) TO FILTERED DATA IN THE OBJECT PROGRA
C     N IS THE TOTAL NUMBER OF DATA POINTS
C     DEL IS THE SAMPLING INTERVAL IN UNIT TIME
C     FRQ IS THE HALF POWER (AMP) POINT IN CYCLES PER UNIT TIME
C     FILTER IS GENERATED BY CONVOLVING ORIGINAL DATA WITH A GAUSSIAN
C     LOW PASS OUTPUT IS THE SMOOTHED DATA
C     HIGH PASS OUTPUT IS THE ORIGINAL DATA MINUS THE SMOOTHED DATA
C     PASS IS THE SIGNAL AFTER A LOW-PASS FILTER
C     HIPASS IS THE SIGNAL AFTER A HIGH PASS FILTER
C     TAILS ON THE ORIGINAL DATA ARE CREATED BY REITERATING FIRST AND LA
C           POINTS. THESE TAILS ARE SUPPRESSED IN THE FILTER OUTPUT.
      DIMENSION X(1),HIPASS(1),PASS(1),XX(1),W(1)
      SIGMA=SQRT( .69315 /(2.0*(3.1416**2.0)*(FRQ**2.0)))
      TP=SQRT(5.0*2.0*(SIGMA**2.0))
      M=TP/DEL
      AM=M
      TP=AM*DEL
      NM=N+M
      N1=N+1
      NM1=N+M+1
      NMM=N+M+M
      M1=M+1
      MM1=M+M+1
      SUM=0.0
      DO 3 I=1,M
      XX(I)=X(1)
    3 CONTINUE
      DO 4 I=NM1,NMM
      XX(I)=X(N)
    4 CONTINUE
      DO 5 I=1,N
      K=I+M
      XX(K)=X(I)
    5 CONTINUE
      DO 6 K=1,MM1
      C=K-1
      TC=C*DEL
      W(K)=1.0/EXP(((TP-TC)**2)/(2.0*(SIGMA**2)))
    6 CONTINUE
      SUM=0.0
      DO 61 K=1,MM1
      SUM=W(K)+SUM
   61 CONTINUE
      SUMA=0.0
      DO 63 K=1,MM1
      W(K)=W(K)/SUM
      SUMA=W(K)+SUMA
   63 CONTINUE
      DO 8 I=1,N
      SUMA=0.0
      DO 7 K=1,MM1
      J=I+K-1
      SUMA=SUMA+XX(J)*W(K)
```

```
    7 CONTINUE                                                              FIL00560
      PASS(I)=SUMA                                                          FIL00570
      HIPASS(I)=X(I)-SUMA                                                   FIL00580
    8 CONTINUE                                                              FIL00590
   10 CONTINUE                                                              FIL00600
   12 CONTINUE                                                              FIL00610
   11 RETURN                                                                FIL00620
      END                                                                   FIL00630
```

```
      SUBROUTINE PASS4(X,XNEW,WEIGHT,NEFF,N,NMOD,DT,DTMOD,
     *     PERIOD,SEL,LXTND ,LSPRS)
C.......................................................................
C
C     ROUTINE BAND-PASS FILTERS BY CONVOLVING THE INPUT SERIES WITH
C     A DAMPED SINE WAVE. FREQUENCY RESPONSE IS GAUSSIAN SHAPED,
C     CENTERED AT THE GIVEN FREQUENCY, WITH A NORMALIZED SELECTIVITY,
C     GIVEN BY SEL .
C
C     SUBPROGRAMS REQUIRED:
C       NONE
C
C.......................................................................
      DIMENSION X(1),XNEW(1),WEIGHT(1)
C.......................................................................
C
C     SUBROUTINE PARAMETERS:
C       X      -ARRAY CONTAINING BOTH INPUT AND OUTPUT SERIES OF FILTER
C       XNEW   -TEMPORARY STORAGE ARRAY (CONTAINS EXTENDED INPUT
C                SERIES, SHOULD BE LARGE ENOUGH TO ALLOW FOR THIS)
C       WEIGHT-TEMPORARY STORAGE ARRAY (CONTAINS FILTER FUNCTION,
C                DIMENSION SHOULD BE GREATER THAN (3*PERIOD)/SEL*DT)+1
C       NEFF   -THE EFFICIENCY PARAMETER: THE FILTER OUTPUTS POINTS
C                AT INTERVALS NEFF*DT (NEFF IS USUALLY 1)
C       N      -NUMBER OF POINTS IN INPUT SERIES
C       NMOD   -NUMBER OF POINTS IN OUTPUT SERIES (NMOD=(N-1)/NEFF+1)
C       DT     -THE SAMPLING INTERVAL BETWEEN POINTS IN INPUT SERIES
C       DTMOD -THE SAMPLING INTERVAL BETWEEN POINTS IN OUTPUT SERIES
C       PERIOD-CENTER PERIOD (CONVERTED IMMEDIATELY TO FRQ=1/PERIOD)
C       SEL    -SELECTIVITY OF THE FILTER: IF FRQ(E) IS THE FREQUENCY
C                AT WHICH THE FILTER RESPONSE IS DOWN TO 1/E OF ITS
C                MAXIMUM VALUE, THEN SEL=(FRQ-FRQ(E))/FRQ
C       LXTND -PARAMETER CONTROLLING TREATMENT OF THE ENDS OF X:
C                =1 ZERO MEAN IS ASSUMED FOR X, ZEROS ARE ADDED TO
C                   EACH END OUT TO 1/2 THE FILTER LENGTH
C                =2 X IS AVERAGED OVER ONE PERIOD INTO THE SERIES
C                   AND THE MEAN USED TO EXTEND THE INPUT SERIES
C       LSPRS -PARAMETER CONTROLLING TREATMENT OF OUTPUT SERIES:
C                =0 EACH POINT WITHIN 1 PERIOD OF EACH END OF THE
C                   SERIES IS MULTIPLIED BY ZERO TO MINIMIZE
C                   TRANSIENTS INTRODUCED BY THE FILTER
C                =1 NO MODIFICATION IS PERFORMED
C
C.......................................................................
      PI=3.141596
      FRQ=1.0/PERIOD
C---->
C---->   TC IS THE FORWARD LENGTH OF THE FILTER IN TIME
C---->   CONSTANTS OF THE DAMPING TERM
C---->
      TC=2.0
C---->
C---->   S IS THE UNNORMALIZED SELECTIVITY
C---->
      S=SEL*FRQ*2.0*PI
```

```
C---->
C---->     TFILT IS THE FORWARD LENGTH OF THE FILTER IN REAL TIME
C---->
      TFILT=TC*4.0/S
C---->
C---->     OMEGA IS THE CENTER FREQUENCY IN RADIANS PER UNIT TIME
C---->
      OMEGA=2.0*PI*FRQ
C---->
C---->     MFILT IS THE NUMBER OF SAMPLING BITS IN 1/2 OF THE FILTER
C---->     TFILT IS ADJUSTED LENGTH OF THE SERIES
C---->     NFILT IS TOTAL NUMBER OF SAMPLING BITS IN THE FILTER
C---->
      MFILT=TFILT/DT
      TFILT=MFILT
      TFILT=TFILT*DT
      NFILT=2*MFILT+1
      AEFF=NEFF
C---->
C---->     THE FILTER FUNCTION IS GENERATED
C---->
      DO 10 I=1,NFILT
      T=I-1
      T=T*DT-TFILT
      WEIGHT(I)=2.0*S*(SQRT(PI))*COS(OMEGA*T)/EXP(S*S*T*T/4.0)
   10 CONTINUE
C---->
C---->     THE ENDS ARE EXTENDED
C---->
      IF(LXTND.EQ.2) GO TO 11
      XEND=0.0
      XBEGIN=0.0
      IF(LXTND.EQ.1) GO TO 21
   11 KEX=1.0/FRQ/DT
      KEX=KEX+1
      SUM=0.0
      AEX=KEX
      DO 100 I=1,KEX
      SUM=X(I)+SUM
  100 CONTINUE
      XBEGIN=SUM/AEX
      KKEX=N-KEX+1
      SUM=0.0
      DO 110 I=KKEX,N
      SUM=X(I)+SUM
  110 CONTINUE
      XEND=SUM/AEX
C---->
C---->     NEW IS THE NUMBER OF POINTS IN THE NEW SERIES
C---->
   21 NEW=N+2*MFILT
      NEND=MFILT+N
      DO 20 I=1,MFILT
      IBEGIN=I
      IEND=I+NEND
```

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      XNEW(IBEGIN)=XBEGIN                                               PAS01110
      XNEW(IEND)=XEND                                                   PAS01120
   20 CONTINUE                                                          PAS01130
C---->                                                                  PAS01140
C---->    THE ORIGINAL SERIES IS ADDED TO THE MIDDLE OF THE NEW SERIES  PAS01150
C---->    XNEW IS THE EXTENDED SERIES                                   PAS01160
C---->                                                                  PAS01170
      DO 30 I=1,N                                                       PAS01180
      J=I+MFILT                                                         PAS01190
      XNEW(J)=X(I)                                                      PAS01200
   30 CONTINUE                                                          PAS01210
C---->                                                                  PAS01220
C---->    THE EXTENDED SERIES IS CONVOLVED WITH THE                     PAS01230
C---->    FILTER IMPULSE RESPONSE FUNCTION                              PAS01240
C---->                                                                  PAS01250
      NMOD=0                                                            PAS01260
      IMOD=0                                                            PAS01270
      DO 40 I=1,N,NEFF                                                  PAS01280
      SUM=0.0                                                           PAS01290
      DO 50 JFILT=1,NFILT                                               PAS01300
      K=I+JFILT-1                                                       PAS01310
      SUM=SUM+XNEW(K)*WEIGHT(JFILT)                                     PAS01320
   50 CONTINUE                                                          PAS01330
      IMOD=IMOD+1                                                       PAS01340
      NMOD=IMOD                                                         PAS01350
      X(IMOD)=DT*SUM/(2.0*PI)                                           PAS01360
   40 CONTINUE                                                          PAS01370
      IF(LSPRS.EQ.1) GO TO 31                                           PAS01380
C---->                                                                  PAS01390
C---->    LTRANS IS THE LENGTH OF THE TRANSIENT                         PAS01400
C---->                                                                  PAS01410
      LTRANS=PERIOD/(DT*AEFF)                                           PAS01420
      LBEGIN=LTRANS+1                                                   PAS01430
      LEND=NMOD-LTRANS                                                  PAS01440
      LEND1=LEND+1                                                      PAS01450
      DO 60 I=1,LTRANS                                                  PAS01460
      X(I)=0.00001                                                      PAS01470
   60 CONTINUE                                                          PAS01480
      DO 80 I=LEND1,NMOD                                                PAS01490
      X(I)=0.00001                                                      PAS01500
   80 CONTINUE                                                          PAS01510
 31   DTMOD=DT*NEFF                                                     PAS01520
      RETURN                                                            PAS01530
      END                                                               PAS01540
```

```
      SUBROUTINE PHILTR (X,Y,LX,LY,DELT,PERIOD,SEL,KEND)
C..........................................................................
C
C     X IS THE ARRAY CONTAINING THE TIME SERIES TO BE FILTERED.
C          ALSO THE FILTERED SERIES IS RETURNED IN X.
C     Y IS A TEMPORARY STORAGE ARRAY. THE DIMENSION OF Y (IN
C          THE MAIN PROGRAM) MUST ALLOW FOR EXTENDING THE X ARRAY
C          BY A PERIOD LENGTH ON EACH END TO ALLOW FOR FILTER
C          SHOCK (KEND=2)
C
C..........................................................................
C
C..........................................................................
C
C     LX IS THE NUMBER OF POINTS CONTAINED IN X.
C     LY IS THE NUMBER OF POINTS CONTAINED IN Y
C     DELT IS THE SAMPLING INTERVAL.
C     PERIOD IS THE CENTER PERIOD OF THE BAND-PASS FILTER.
C     SEL IS THE SELECTIVITY OF THE FILTER.  IT IS DEFINED
C          AS (F2-F1)/FO WHERE FO IS THE CENTER OF THE BAND;
C          F1 AND F2 ARE THE FREQUENCIES TO EACH SIDE OF FO
C          WHERE THE AMPLITUDE RESPONSE OF THE FILTER IS EQUAL
C          TO 1/2.  THE RESPONSE AT FO IS 1.
C     KEND: =0, THE X ARRAY IS FILTERED ASSUMING THAT THE VALUES
C                ARE ZERO OUTSIDE THE ARRAY.  THE ENDS ARE NOT
C                EXTENDED.
C           =1, A COSINE TAPER IS APPLIED TO THE ENDS OF THE INPUT
C                SERIES.  THE ENDS ARE NOT EXTENDED.
C           =2, THE ENDS OF THE INPUT SERIES ARE EXTENDED BY ONE
C                CENTER PERIOD AND A COSINE TAPER IS APPLIED TO THE
C                EXTENSION.
C
COMMENT:  THE FILTER DOES NOT HAVE ZERO PHASE SHIFT, SO THE DATA
C          IS FILTERED FORWARD IN TIME AND THEN THE FILTER IS
C          APPLIED IN THE REVERSE DIRECTION TO OFFSET THE PHASE SHIFT.
C
C      SUBPROGRAMS REQUIRED:
C        NONE
C
C..........................................................................
      DIMENSION X(LX),Y(LY)
      COMPLEX Z0,Z0C,Z1,ONE,C
      INTEGER EXTEND,TAPER
      FO=1.0/PERIOD
      SELECT = SEL*SQRT(2.)*DELT*FO*1.8394
      C=(0.0,1.0)
      ONE=(1.0,0.0)
      PI=3.1415926
      EXTEND=0
      Z0=(1.0+SELECT)*CEXP(-2.0*PI*C*FO*DELT)
      Z0C=CONJG(Z0)
      Z1=CEXP(-2.0*PI*C*FO*DELT)
      H0=(CABS(Z1-Z0)*CABS(Z1-Z0C))/(CABS(Z1-ONE)*CABS(Z1+ONE))
      A0=H0/REAL(Z0*Z0C)
      A2=A0
```

```
      B1=(REAL(ZO+ZOC))/(REAL(ZO*ZOC))
      B2=1.0/(REAL(ZO*ZOC))
      TAPER = 1
      LXNEW=LX
      IF(KEND.EQ.0) GO TO 35
      IF(KEND.EQ.1) GO TO 25
      EXTEND=PERIOD/DELT+1
C---->
C---->    EXTEND THE ENDS OF THE INPUT TIME SERIES
C---->
      DO 10 IL=1,LX
      X(LX+EXTEND-IL+1)=X(LX-IL+1)
10    CONTINUE
      DO 20 IE=1,EXTEND
      X(IE)=X(EXTEND+1)
      X(LX+EXTEND+IE)=X(LX+EXTEND)
20    CONTINUE
      LXNEW=LX+2*EXTEND
25    CONTINUE
C---->
C---->    APPLY A COSINE TAPER TO EITHER THE INPUT OR EXTENDED
C---->    TIME SERIES
C---->
      TAPER= PERIOD/(3.0*DELT)+1
      DO 30 IT=1,TAPER
      THETA=(PI/2.0)*(TAPER-IT+1)/TAPER
      X(IT)=X(TAPER+1)*COS(THETA)
      X(LXNEW-IT+1)=X(LXNEW-TAPER)*COS(THETA)
30    CONTINUE
35    CONTINUE
C---->
C---->    FILTER IN THE DIRECTION OF INCREASING TIME
C---->
      Y(1)=-AO*X(1)
      Y(2)=-AO*X(2)+B1*Y(1)
      DO 40 IL=3,LXNEW
      Y(IL)=-AO*X(IL)+A2*X(IL-2)+B1*Y(IL-1)-B2*Y(IL-2)
40    CONTINUE
      DO 50 IT=1,TAPER
      THETA=(PI/2.0)*(TAPER-IT+1)/TAPER
      Y(IT)=Y(TAPER+1)*COS(THETA)
      Y(LXNEW-IT+1)=Y(LXNEW-TAPER)*COS(THETA)
50    CONTINUE
C---->
C---->    FILTER IN THE DIRECTION OF DECREASING TIME
C---->
      X(LXNEW)=-AO*Y(LXNEW)
      X(LXNEW-1)=-AO*Y(LXNEW-1)+B1*X(LXNEW)
      DO 60 IL=3,LXNEW
      X(LXNEW-IL+1)=-AO*Y(LXNEW-IL+1)+A2*Y(LXNEW-IL+3)
     *               +B1*X(LXNEW-IL+2)-B2*X(LXNEW-IL+3)
60    CONTINUE
      DO 70 IL=1,LX
      X(IL)=X(EXTEND+IL)
70    CONTINUE
```

```
      RETURN                                                            PHI01050
      END                                                               PHI01060
```

```
C...........................................................................
      SUBROUTINE SMOOTH(X,N,M)
C...........................................................................
C
C     PROGRAM TO SMOOTH DATA USING EQUALLY WEIGHTED RUNNING AVERAGE
C
C                    X IS THE INPUT DATA SERIES.
C                    N IS THE NUMBER OF INPUT DATA POINTS.
C                    M IS THE NUMBER OF POINTS IN THE AVERAGING INTERVAL.
C
C...........................................................................
      DIMENSION X(1),SMUTH(3000)
      A=M
      IBEGIN=(M+1)/2
      IEND=N-IBEGIN+1
      LM=(M-1)/2
      DO 10 I=IBEGIN,IEND
      SUM=0.0
      DO 20 LSMUTH=1,M
      L=LSMUTH-1
      J=I+L-LM
      SUM=SUM+X(J)
   20 CONTINUE
      SMUTH(I)=SUM/A
   10 CONTINUE
C
C          THIS STEP OVEREMPHASIZES SMOOTHING AT ENDPOINTS.
      DO 30 I=1,N
      IF(I.LT.IBEGIN)SMUTH(I)=SMUTH(IBEGIN)
      IF(I.GT.IEND)SMUTH(I)=SMUTH(IEND)
   30 CONTINUE
C
C          THIS STEP DESTROYS THE ORIGINAL DATA SERIES,REPLACING IT
C               WITH THE SMOOTHED SERIES.
      DO 40 I=1,N
      X(I)=SMUTH(I)
   40 CONTINUE
      RETURN
      END
      SUBROUTINE SPLIT(N,ISIT)
```